THE PHYSIOLOGICAL AND PERCEPTUAL RESPONSES TO CYCLING EXERCISE IN A FULLY IMMERSIVE VIRTUAL ENVIRONMENT

by

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Abstract

An innovative piece of digital technology which has recently come to the attention of sports scientists as a potential ergogenic aid is the use of immersive virtual reality (VR) technology. Whilst the effects of VR on performance have begun to be explored, the physiological and perceptual responses to exercise when combined with VR remain relatively unknown. Accordingly, this study investigated both the physiological and perceptual responses to exercise in a fully immersive virtual environment viewed through a stereoscopic head-mounted display. Thirteen recreationally active males (*n*=12) and females (*n*=1) (age = 24.9 ± 4.6 y; body mass = 78.7 ± 6.3 kg; stature = 178.6 ± 3.7 cm; VO_{2max} = 55.1 ± 7.1 $ml \cdot kg^{-1} \cdot min^{-1}$) completed a time to exhaustion (TTE) test under control (CON) and virtual reality (VR) conditions in a repeated measures randomized crossover design. Effect sizes (ES) and magnitude-based inferences were calculated for all variables between conditions using a predesigned spreadsheet (Batterham & Cox, 2006). TTE (ES = 0.78; ±0.37), enjoyment (ES = 0.85; ±0.49) and positive affect (PA) (ES = 0.78; ±0.65) were all greater in the VR compared to CON condition. HR and RPE, analyzed over a 6 minute isotime, were lower at minute two only (ES = 0.33; ±0.38) and (ES = 0.88; ±0.52) respectively, in the VR compared to CON condition. There were no changes in VO_2 peak, b[La] and negative affect (NA) between conditions. The use of a fully immersive VR headset in combination with a traditional cycling task was shown to elicit improvements in TTE performance and increase affective responses and enjoyment of the exercise, likely due to a dissociative effect. These findings support the use of fully immersive VR in the exercise domain as an ergogenic aid.

Declaration

No portion of the work referred to in this Research Project has been submitted in support of an application for another degree or qualification of this, or any other University or institute of learning.

The project was supervised by a member of academic staff, but is essentially the work of the author.

Copyright in text of this Research Project rests with the author. The ownership of any intellectual property rights which may be described in this thesis is vested in the University of Chester and may not be made available to any third parties without the written permission of the University.

Signed: 

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Chapter 1

Introduction

1.1 Performance and Ergogenic Aids

Sports scientists and practitioners spend endless amounts of time trying to ensure that athletes training and preparation strategies are appropriate to elicit optimal performance (Kilduff et al., 2013). In the perpetual quest for better performance, an increasingly diverse range of new and novel ergogenic aids are being adopted (McClung & Collins, 2007). These include the use of several digital technology related aids such as music and video which, due to advancements in technology, have been brought closer than ever before to sports and exercise environments (Barwood, Weston, Thelwell & Page, 2009).

According to the available evidence, music and video elicit a number of positive psychological (motivation, mood, affect, rating of perceived exertion (RPE)) and psychophysiological effects (changes in heart rate (HR), breathing frequency, testosterone concentrations) (Cook & Crewther, 2012a; Barwood et al., 2009; Karageorghis & Priest, 2012). These changes have combined to produce a number of improvements in performance including increased peak and mean power output (Jarraya et al., 2012; Chtourou et al., 2012; Stork, Kwan, Gibala & Martin, 2015), increased time to exhaustion (Terry, Karageorghis, Saha & D'Auria, 2012; Nakamura, Pereira, Papini, Nakamura & Kokubun, 2010), improved time trial performance (Atkinson, Wilson & Eubank, 2004; Elliot, 2007; Lin & Lu, 2013), and improved sprint and squat performance (Cook & Crewther 2012b).

It is evident that the addition of extra sensory stimuli, via digital technology, can alter perception of effort and subsequently influence physiological responses to exercise, thus providing a means for enhancing performance. A new innovative piece of technology, which has recently come to the attention of sports scientists as a potential ergogenic aid, is the use of virtual reality (VR) technology.

1.2 Virtual Reality

Virtual reality refers to an alternate world, a substitute reality, filled with three-dimensional computer generated images that can be explored and interacted with by a person (Banos et al., 2000; Steuer, Biocca & Levy, 1995). These interactive environments can artificially create a number of sensory experiences including sight and hearing (Barfield, Zeltzer, Sheridan & Slater, 1995). VR was originally conceived as a digitally created space that could only be accessed by humans via highly sophisticated computer equipment such as window (computer screens) and cave (enclosure filled with large screens) systems (Biocca, Kim & Levy, 1995). However, the VR interface has made a number of advancements over the years with immersive VR systems, including those where users wear stereoscopic head-mounted displays that fully immerse a number of the senses in computer generated stimuli, now available (Biocca & Delaney, 1995). Head-mounted devices allow the matching of participants' proprioceptive feedback about body movements with information generated on screen thus enabling a person to look at a computer generated environment in a manner similar to that of the real world, making this a natural, intuitive interface (Sherman & Craig, 2002).

This natural interface increases the level of immersion considerably when compared to previous VR systems. Immersion has been described as the objectively measurable and quantifiable properties of a virtual environment (Schubert, Friedmann & Regenbrecht, 2001). In other words immersion is the extent to which computer displays are capable of delivering an inclusive and vivid illusion of reality to the senses of the VR participant (Slater & Wilbur, 1997). The distinguishing feature of immersive virtual environments compared with desktop displays is the greater feeling of presence experienced by users (Slater & Wilbur, 1997). Presence is conceptualised as the experiential counterpart of immersion (Steuer et al., 1995). It has been defined as a state of consciousness, the subjective sense of 'being there' in a mediated environment (Bowman & McMahan, 2007). A number of perceptual factors contribute to generating this sense, including some or all sensory channels (Gibson, 1966). Presence is generally considered a positive outcome of immersive environments, leading to engagement and more intense enjoyment (Ijsselsteijn, de Kort, Westernik, de Jager & Bonants, 2004).

1.3 The Application of Virtual Reality

One of the reasons that VR technology has attracted so much interest is that it offers enormous benefits to a number of different application areas including gaming (Zyda, 2005), medicine (Muller-Wittig, 2011), aviation (Stedmon & Stone, 2001) and education (Choi, 2016). Effectively, VR can simulate real environments without the risks arising from errors (Kim & Park, 2013). Miles, Pop, Watt, Lawrence and John (2012) identified a number of studies using VR for the training of sports related skills such as throwing and catching in rugby, baseball and handball. However, whilst there is evidence to suggest that the improvement of motor control skills in ball sports is possible Miles et al. (2012) concluded that a virtual environment is currently best suited for the training of anticipation and decision making skills. Bergamasco, Bardy and Gopher (2012) support this view and suggest that VR is a useful method for skill acquisition. This is demonstrated by a number of sports teams, including NBA and NFL teams Dallas Cowboys and Washington Wizards, incorporating a VR training headset (STRIVR) into training and preparation so that athletes can re-live sessions/games, practice plays/formations, and even take endless free throws/kicks. Despite the progression of VR into the sporting environment, limited empirical research exists on VR’s effect on performance.

1.4 Virtual Reality and Exercise

In recent years VR has been combined with a growing number of traditional exercise tasks including treadmill running (Nunes, Nedel & Roesler, 2014), ergometer rowing (Hoffman, Filippeschi, Ruffaldi & Bardy, 2014; Murray, Neumann, Moffitt & Thomas, 2016), and stationery cycling (Legrand, Joly, Bertucci, Soudain-Pineau & Marcel, 2011; Mestre, Dagonneau & Mercier, 2011a; Plante, Aldridge, Bogden & Hanelin 2003a; Plante et al., 2003b). This body of research has indicated that the addition of VR can increase physical exertion in several ways, including greater revolutions per minute (RPM), greater power output, improved time trial performance and also increased physical exertion in the form of HR and RPE. Mestre et al. (2011a) suggested that VR exerted its influence on performance by having a dissociative effect. Similarly, performance improvements have also been attributed to reports of higher levels of affect and enjoyment which may be a consequence of dissociation (Murray et al., 2016). Whilst improvements in performance and reports of higher enjoyment levels have been found, minimal physiological measurements were recorded and thus the potential physiological mechanisms behind the greater levels of exertion remain largely unknown.

An important consideration of the aforementioned research on the application of VR in a sport and exercise setting is the minimally immersive VR interfaces used such as monitors or projections. A study by Ijsselsteijn et al. (2004) which manipulated the level of immersion using different points of view found that participants cycled faster, rated their experience of presence higher and found the task more enjoyable when cycling from the point of view of the rider (considered high immersion) when compared to a birds eye view (considered low immersion). This indicates that the level of immersion might exert an additive effect to further enhance presence in a virtual environment thus enhancing the effects of exercise within a VR environment (Ijsselsteijn et al., 2004; Murray et al., 2016). This may also be true when using minimally immersive VR interfaces whilst exercising compared to potentially using fully immersive VR headsets.

1.5 Rationale and Hypotheses

Despite a number of studies finding positive effects on performance and enjoyment of exercise when combining VR with exercise, these studies used VR interfaces which have been shown to elicit poorer levels of immersion and presence than the head-mounted displays which have emerged in recent times. Accordingly, the aim of this study was to investigate the perceptual responses to exercise in a fully immersive virtual environment. The physiological responses to exercise in a VR environment, which are currently poorly understood, will also be explored. It is hypothesised that:

(a) Participants will exercise for longer whilst immersed in the virtual environment.
(b) Physiological responses to exercise in the VR condition will be greater i.e. increased HR and VO_{2}, and higher blood lactate levels due to greater levels of physical exertion.
(c) Exercising in the virtual environment will reduce RPE, enhance affect and increase enjoyment.

Chapter 2

Methods

Prior to commencement of this study, ethical approval was sought from and approved by the Faculty of Science and Engineering Research Ethics Committee, University of Chester (Appendix A).

2.1 Participants

An appropriate sample size was calculated for the study at fourteen using a statistical power analysis program (G*Power 3.1.9.2) (Faul, Erdfelder, Lang & Buchner, 2007). Subsequently, thirteen recreationally actives males (*n*=12) and females (*n*=1) (age = 24.9 ± 4.6 y; body mass = 78.7 ± 6.3 kg; stature = 178.6 ± 3.7 cm; VO_{2max} = 55.1 ± 7.1 $ml \cdot kg^{-1} \cdot min^{-1}$) were recruited for the study. Participants were provided with a written explanation of the study (Appendix B) before each reading and signing an informed consent form (Appendix C). A pre-test health questionnaire was completed by each individual prior to the commencement of testing to check for any contraindications to exercise (Appendix D).

2.2 Study Design

A repeated measures randomized crossover design was employed requiring three visits to the laboratory (Figure 2.1). On the first visit, participants performed a fast ramp VO_{2max} test to determine exercise intensity for subsequent trials, followed by a familiarisation period with the VR headset. For each visit thereafter (visit 2 and 3) participants performed a time to exhaustion test (TTE), at a power output corresponding to 80% of that achieved at VO_{2max}, under one of two different conditions; a control condition (CON) and a virtual reality condition (VR). The order of conditions was randomised using a pseudo-random number generator (Research Randomizer (Version 4.0)) (Urbaniak & Plous, 2013). Prior to, and immediately following, each TTE test participants completed an I-PANAS-SF questionnaire to assess their level of positive (PA) and negative (NA) affect. Participants also had their resting heart rate (HR) and blood lactate concentration (b[La]) recorded prior to exercise. Measurements of HR were also taken at each two minute point throughout each TTE test as well as ratings of perceived exertion (RPE). Upon completion of each test, TTE was recorded and a b[La] sample taken before participants completed the PACES and Presence questionnaires.

Each participant completed testing over a 2 week period with a minimum of 48 hours recovery between visits to allow for adequate recovery time. Participants were provided with a written food diary (Appendix E) prior to testing and asked to record dietary intake 24 hours prior to visit 2. The food diary was returned to participants prior to subsequent visits in order to replicate previous dietary intake. Participants were asked to refrain from consuming products containing caffeine or stimulants during this time and also to refrain from exercising in the 48 hours prior to testing. Laboratory conditions remained consistent throughout with temperatures kept between 18 and 22° and humidity between 45 and 60%, on each day of testing to prevent any potential thermoregulatory associated physiological changes occurring (Lim, Byrne & Lee, 2008).

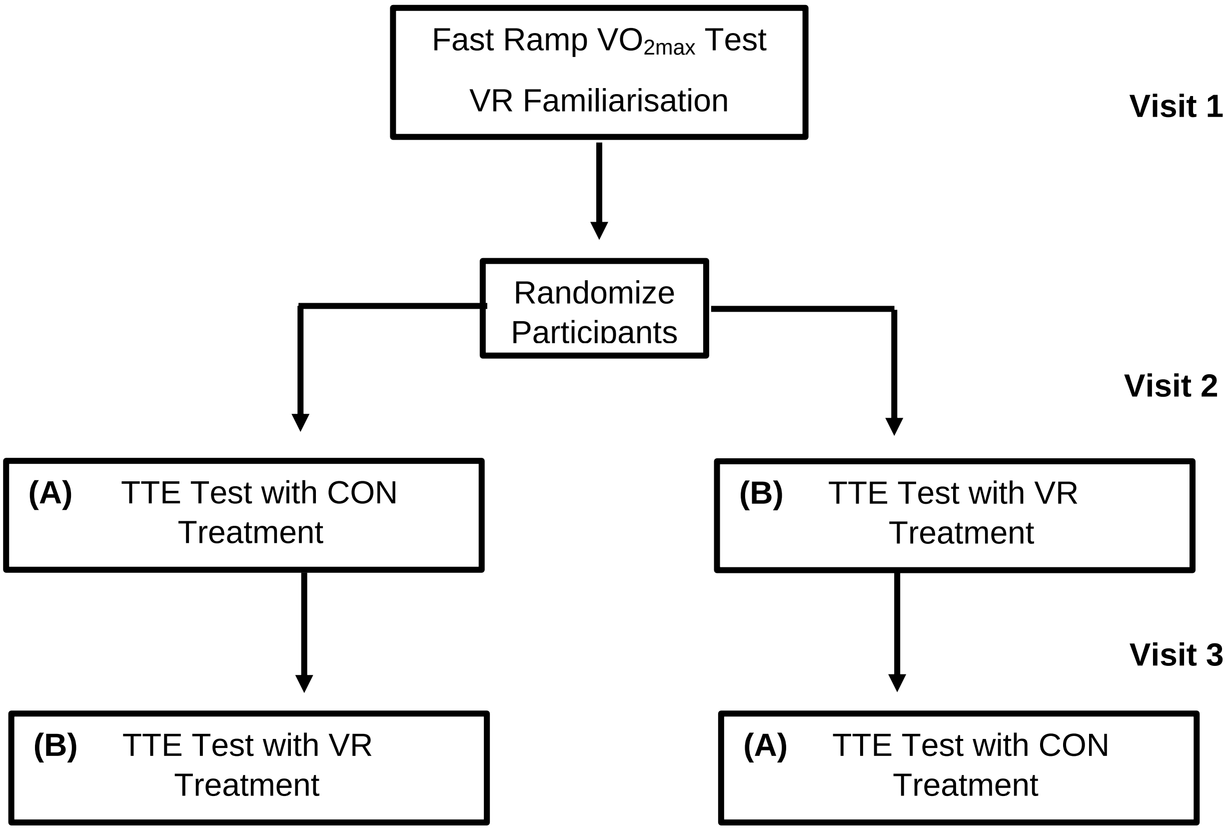

Figure 2.1 Schematic of study design

2.3 Procedures

2.3.1 Fast Ramp VO_{2max} Test

VO_{2max} was measured during a fast ramp protocol to determine individualized exercise intensities at 80% of power output achieved at VO_{2max} (peak power output (PPO)) for subsequent TTE trials. Participants were familiarised with the cycle ergometer (Lode, Excalibur (Sport), Lode BV Groningen, Netherlands) prior to testing, (Cooke, 2009). A pre-programmed ramp protocol was selected from the lode ergometry manager (LEM Version 8.x), beginning at 50 W and 100 W for females and males respectively (Laursen, Blanchard & Jenkins, 2002). Both protocols incrementally increased by 1 W every 3 seconds (20 W/min). Recording began at 25 revolutions per minute (RPM) and continued throughout until completion. The protocol was terminated upon volitional exhaustion or once participants cadence dropped below 50 RPM. VO_2 and HR were recorded throughout using an online portable gas analyser (Oxycon Pro, Viasys, Viasys Healthcare, Hoechberg, Germany) and HR monitor (Polar Electro, Oy, Finland) respectively. Rating of perceive exertion (RPE) was indicated by participants in the seconds prior to exhaustion using Borg's (1998) RPE scale. A fingertip capillary blood sample was taken immediately post-test and b[La] analysed using a portable lactate analyser (Arkray, Lactate Pro, Arkray, Kyoto, Japan). Collectively, the data was checked against the British Association of Sport and Exercise Sciences (BASES) criteria for establishing VO_{2max} (Bird & Davison, 1997) (Appendix F).

2.3.2 Time-To-Exhaustion Test (TTE)

Participants warmed-up at 40% of peak power output for a duration of 3 minutes on a cycle ergometer (Lode, Excalibur (Sport), Lode BV Groningen, Netherlands) followed by a continuous workload corresponding to 80% of PPO (Marcora, Staiano & Manning, 2009). A cadence of between 60 and 100 RPM was freely chosen by participants. At each two minute point throughout each TTE test, HR and RPE were measured and recorded. In the CON condition they were recorded in the same manner as the VO_{2max} test detailed above, whilst in the VR condition the RPE scale appeared on screen. VO_{2max} was measured continuously throughout all trials. TTE was recorded as the time from the commencement of the 80% of PPO workload until volitional exhaustion. Upon cessation of testing participants immediately began a cool down until HR returned below 100bpm. b[La] was measured 4 minutes post-test. This high-intensity constant power cycling test has been used within a number of experimental studies and has been shown to have similar sensitivity to changes in endurance performance as that of time-trials (Amann, Hopkins & Marcora, 2008).

2.4 Treatments

2.4.1 Control Treatment (CON)

Participants performed a TTE test under normal laboratory conditions with no additional sensory stimuli (no VR headset). Background noise was kept to a minimum as to not distract nor motivate participants. No verbal encouragement was provided by the researcher.

2.4.2 Experimental Treatment (VR)

The experimental treatment involved participants wearing a head-mounted VR display headset (Oculus Rift DK2, Oculus VR, LLC, Menlo Park, California, United States) with accompanying audio played via noise cancelling headphones (Beats Studio, Beats Electronics LLC, Culver City, California, USA). Sounds included the sound of a cycling bike and nature such as birds tweeting, and were interrupted only at each two minute point where a pre-recorded message asked participants to look down at the RPE scale and indicate their RPE.. A positional tracking system (Constellation) was used to optically track the position of the users head via external infared sensors.

2.4.2.1 Description of Virtual Environment

The VR headset displayed a pre-designed computer generated environment depicting a straight road, flanked by an off road desert type sand, under a bright blue sky with a visible sun. Participants could move their head freely and visually explore the virtual environment, thus potentially feeling present in the environment to varying degrees. The display did not show any quantitative information relating to performance, such as time elapsed, RPM, or heart rate.

Figure 2.2 Participants performing a TTE test in VR treatment

2.5 Questionnaires

Participants completed a brief Likert scale questionnaire called the International Positive and Negative Affect Schedule Short Form (I-PANAS-SF) (Appendix G) prior to, and immediately following, each TTE test. The questionnaire, developed by Thompson (2007) was employed to measure positive and negative dimensions of affect on arrival to the lab and resultant levels of affect arising from the TTE tests. Participants also completed the Physical Activity Enjoyment Scale (PACES) questionnaire (Motl et al., 2001) (Appendix H) immediately following each TTE test. PACES, the most widely used measure of physical activity enjoyment (Mullen et al., 2011), was used to form a unidimensional measure of enjoyment of the exercise/environment. Finally, participants completed the Presence Questionnaire (Witmer & Singer, 1998) (Appendix I) upon completion of the TTE test, which measured the degree to which individuals experienced presence in the virtual environment. For a more detailed description of each questionnaire, see Appendix J.

2.6 Statistical Analyses

Effect sizes (ES) and magnitude-based inferences were calculated for all variables between conditions (Batterham & Hopkins, 2006). An isotime of 6 minutes (the first 6 minutes of each TTE test) was used to include all participants in HR and RPE analysis. Thresholds for the magnitude of the observed change for each variable was determined as the between participants SD in that variable x 0.2. 0.6 and 1.2 which represents a small, moderate and large effect respectively (Hopkins, Marshall, Batterham & Hanin, 2009). Threshold probabilities for a meaningful effect based on 90% confidence intervals were <0.5% most unlikely, 0.5% to 5% very unlikely, 5% to 25% unlikely, 25% to 75% possibly, 75% to 95% likely, 95% to 99.5% very likely, and 99.5% most likely. All calculations were completed using a predesigned spreadsheet (Batterham & Cox, 2006). Furthermore, Pearson's correlational analysis of presence and TTE was performed using SPSS software (SPSS INC, IBM, Chicago, USA) with the Alpha (α) level for the evaluation of statistical significance set at $p<0.05$..

Chapter 3

Results

3.1 Performance

Time to exhaustion (TTE) in CON and VR conditions is shown in Figure 3.1. There was a *very likely* moderate increase in TTE in VR compared to CON condition (598.8 ± 133.3 vs 498.8 ± 119.5 s) (ES = 0.78; ±0.37).

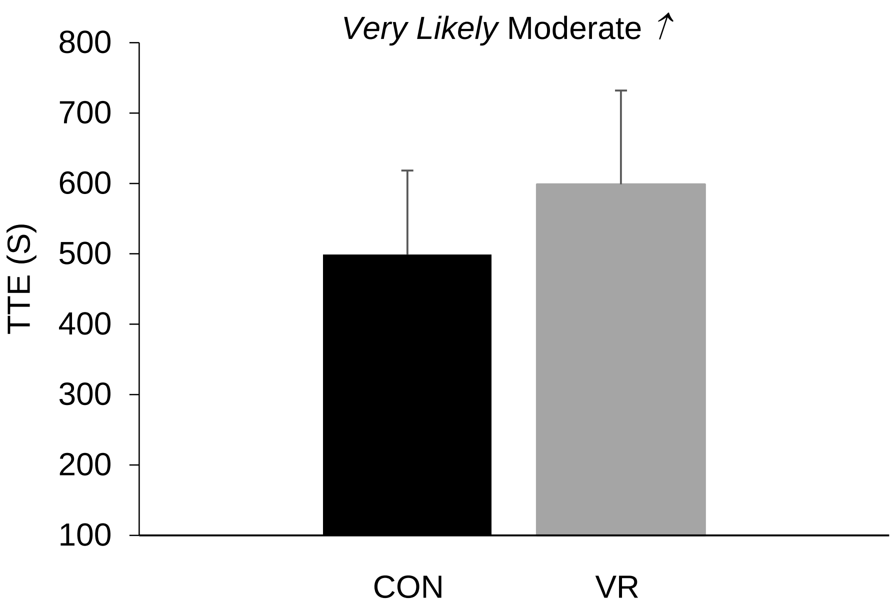

Figure 3.1 Time to exhaustion recorded in CON ■ and VR ■ conditions. Values presented as mean ± standard deviation with qualitative descriptor between trials included.

3.2 Physiological Measures

The physiological responses to the TTE test in CON and VR conditions are shown in Figure 3.2. There were *possibly* trivial differences in HR between CON and VR conditions at minute 6 (ES = 0.15; ±0.32) whilst it is *unclear* whether there were differences in HR between conditions at rest (ES = 0.01; ±0.38) and at minute 4 (ES = 0.16; ±0.38) (Figure 3.2 (a)). There was a *possibly* small increase in HR at minute 2 of the isotime in CON compared to VR condition (163.1 ± 11.5 vs 159.1 ± 15.5 $b.min^{-1}$; ES = 0.33; ±0.38) (Figure 3.2 (a)).

There was a *likely* trivial effect of VR on VO_2 peak when compared to CON (4333.6 ± 465.5 vs 4283.4 ± 650.7 ml/min^{-1}; ES = 0.07; ±0.24) (Figure 3.2 (b)). The difference in b[La] between CON and VR conditions pre-test was *unclear* (1.35 ± 0.38 vs 1.22 ± 0.2 mmol/l; ES = 0.32; ±0.54) (Figure 3.2 (c)). Analysis of post-test b[La] also showed that differences between CON and VR conditions were *unclear* (12.35 ± 3.52 vs 11.79 ± 2.75 mmol/l; ES = 0.15; ±0.49) (Figure 3.2 (c)).

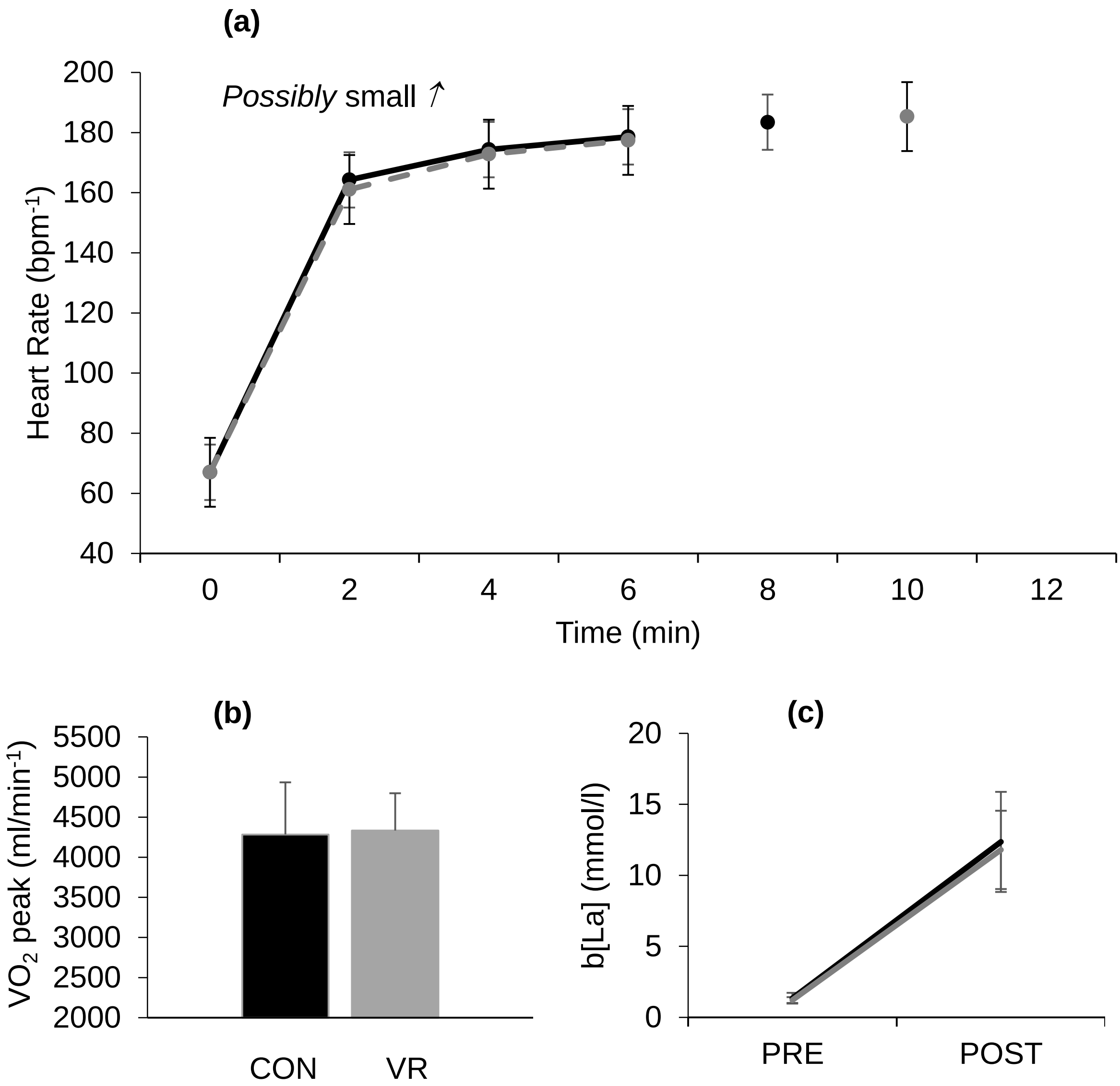

Figure 3.2 Physiological responses to the TTE test in CON and VR conditions. **(a)** Heart rate at each two minute point of the selected 6 minute isotime. **(b)** VO_2 peak during the TTE test. **(c)** Change in blood lactate concentration from pre to post TTE test. Values presented as mean ± standard deviation with qualitative descriptor between trials included.

3.3 Perceptual Measures

Perceptual responses to the TTE test in CON and VR conditions are shown in Figure 3.3 and Figure 3.4. There were no differences in RPE between conditions at rest and at exhaustion. At minutes 4 (16.2 ± 1.3 vs 16.5 ± 0.8; ES = 0.46; ±0.62) and 6 (18.2 ± 1.1 vs 18.7 ± 0.9; ES = 0.46; ±0.43) of the selected isotime RPE was *likely* lower in the VR compared to CON condition (Figure 3.3). RPE was *very likely* lower at minute 2 in the VR compared to CON condition (13.1 ± 1.3 vs 14.3 ± 1.3; ES = 0.88; ±0.52) (Figure 3.3).

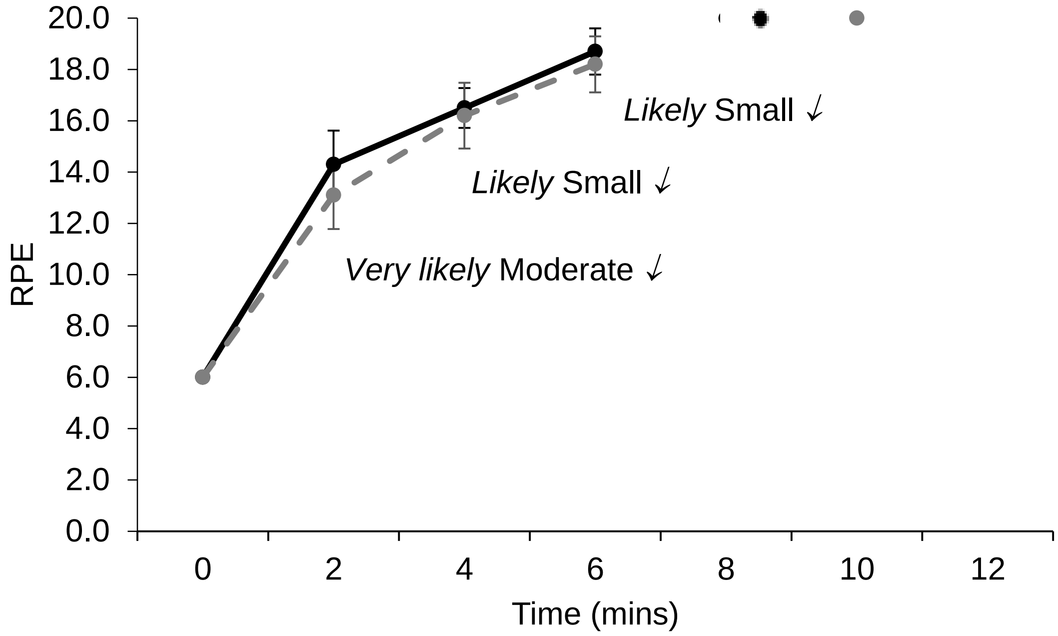

Figure 3.3 RPE at each two minute point of the selected 6 minute isotime CON ■ and VR ■ conditions. Values presented as mean ± standard deviation with qualitative descriptor between trials included.

In the VR condition there was a *very likely* moderate increase in the level of enjoyment experienced, when compared to CON condition (29.4 ± 6.8 vs 16.2 ± 14.5; ES = 0.85; ±0.49) (Figure 3.4 (a)). PA increased from pre to post exercise at a greater rate in the VR condition. There was *very likely* large increase in PA in the VR condition from pre to post exercise (14.23 ± 4.25 vs 20.54 ± 3.84; ES = 0.78; ±0.65) compared to a *likely* moderate increase in PA in CON condition (14.69 ± 3.59 vs 17.69 ± 4.19; ES = 1.39; ±0.76) (Figure 3.4 (b)). It was *unclear* whether there were differences in NA from pre to post exercise in both VR (6.31 ± 1.65 vs 6.1 ± 1.44; ES = 0.13; ±0.49) and CON (6.46 ± 1.61 vs 6.54 ± 2.07; ES = 0.04; ±0.6) conditions (Figure 3.4 (c)).

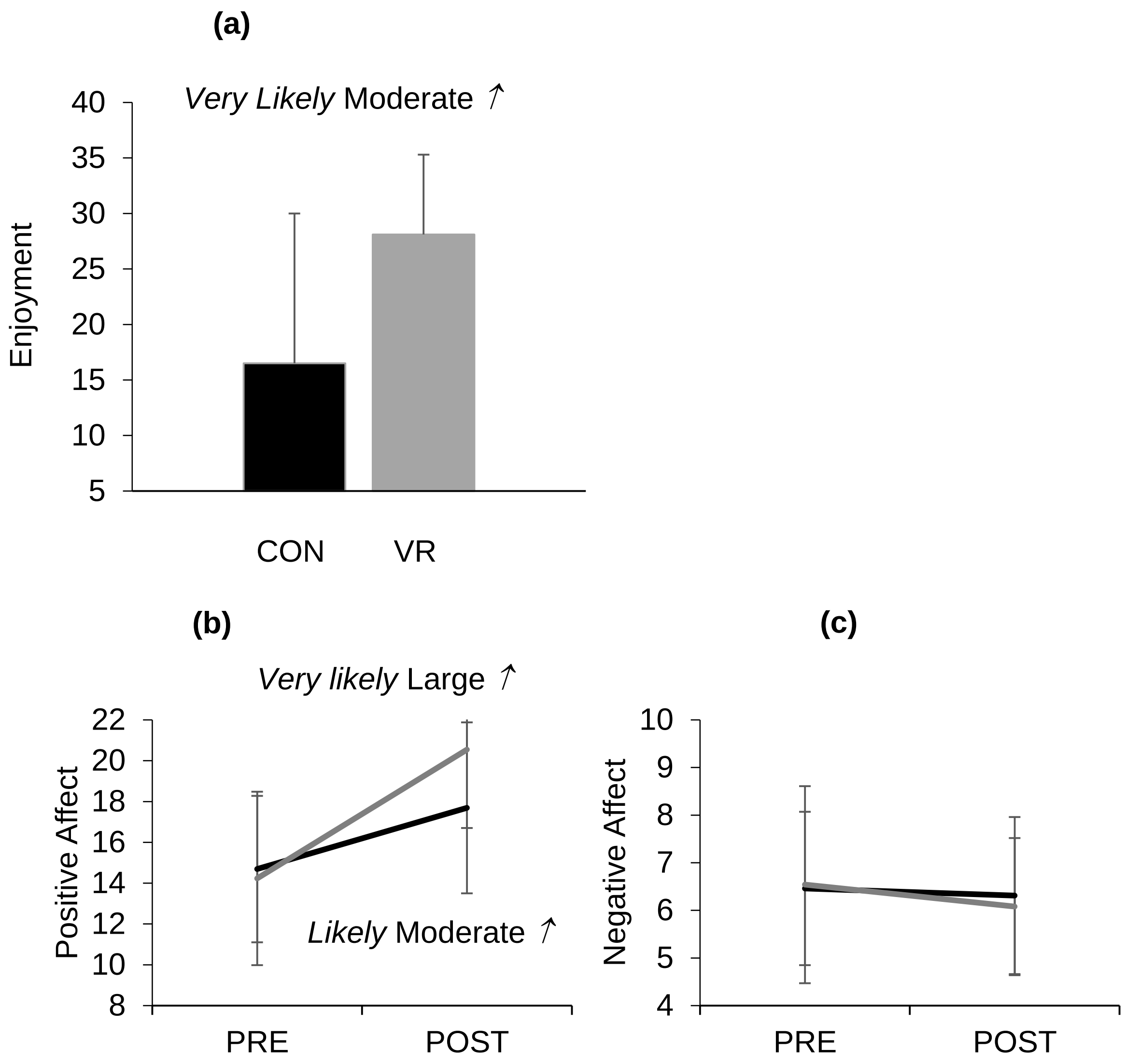

Figure 3.4 Perceptual responses to the TTE test in CON ■ and VR ■ conditions. **(a)** Enjoyment of the physical activity **(b)** Positive affect pre and post TTE test **(c)** Negative affect pre and post TTE test. Values presented as mean ± standard deviation with qualitative descriptor between trials included.

3.4 Presence

Pearson's Correlation analysis of TTE times in VR condition and presence questionnaire scores indicated a non-significant weak to moderate positive relationship between variables (*r* = 0.157; *p*>0.05) (Figure 3.5).

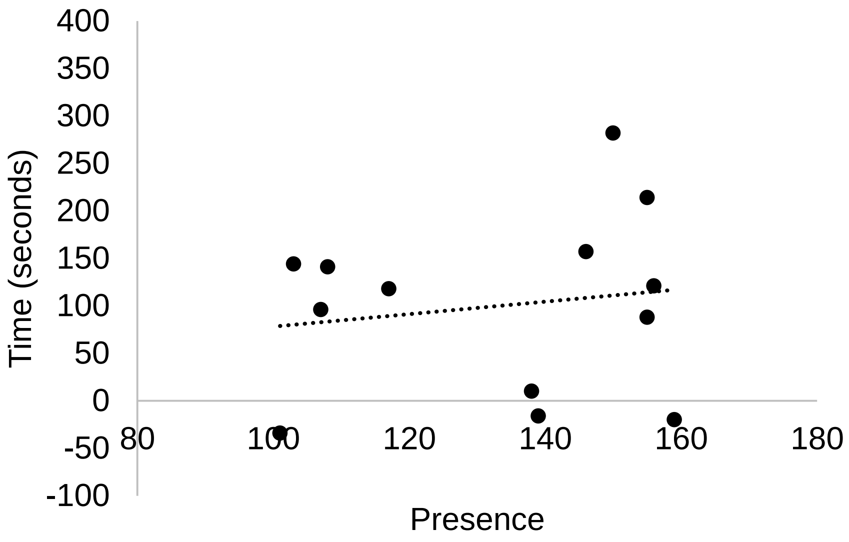

Figure 3.5 Scatterplot of TTE times and PQ scores for each participant involved in the study.

Chapter 4

Discussion

This study examined the physiological, perceptual and performance responses to exercise performed with and without the use of a fully immersive VR headset. The main finding arising from the study is that utilising a VR headset during exercise improved performance, measured as TTE during high-intensity constant load cycling exercise. The underpinning mechanisms for this performance improvement appear to be the lower levels of perceived exertion and greater levels of PA and enjoyment experienced when exercising with VR.

4.1 Performance

The use of a VR headset during high-intensity cycling exercise resulted in a ~ 20% improvement in performance. This improvement in performance is in agreement with the emerging literature on the use of VR, alongside traditional exercise tasks, as a performance enhancing ergogenic aid. Hoffman et al. (2014) found that participants completed a 2000m rowing time trial in fewer seconds whilst performing the task in a virtual environment when compared to a control condition. Murray et al. (2016) also found improvements in performance whilst rowing in a virtual environment compared to a no VR control condition in the form of greater distance achieved over a 9 minute period and a greater mean power output. Despite both studies using a rowing exercise, the findings are likely to generalise to other aerobic exercises such as the one used in the present study.

A study by MacRae (2003) did utilise a cycling task in their VR condition, played via a desktop VR system, and found average speed and distance covered were significantly improved (approximately 50%). However, their interactive virtual environment was coupled with music, providing an additional stimulus compared to the VR condition in the current study and thus performance improvements cannot be solely attributed to the use of VR. The addition of multiple extra stimuli, an approach explored in a similar setting by Loizou and Karageorghis (2015), and its associated performance enhancement, is an interesting finding that may lead to greater performance improvements than the use of VR alone.

4.2 The Physiological Responses to Exercise in a Virtual Environment

4.2.1 Heart Rate

HR increased in a similar fashion across each two minute period of the isotime selected from the TTE test bar minute two where there was a *possibly* small increase in HR in CON above that in the VR condition. Of the studies which incorporated measures of HR into their methodology Plante et al. (2003a) found a slight increase (3%) in HR when cycling at a moderate intensity (60-70% max HR) in a VR computer bicycle condition when compared to a cycling only condition. However, the exercise intensity was noticeably lower than that of the present study and thus may have contributed somewhat to the changes, albeit small, in HR. In comparison, Murray et al. (2016) found that HR was lower whilst exercising in a VR condition despite a greater power output and an overall improvement in performance. It was expected that the use of VR would reduce HR at low intensities (i.e. minute 2) and increase the HR response later in the TTE test due to an increased work output. However, it may be a positive outcome that performance improved in the VR condition despite no apparent additional physiological cost in the form of an elevated HR at minutes 4 and 6.

4.2.2 VO_2 Peak and Blood Lactate

Peak VO_2 attained during the TTE test and changes in b[La] from pre to post-test also did not differ between VR and CON conditions. During heavy or high-intensity exercise VO_2 continues to rise until a delayed steady state/plateau is achieved or exhaustion ensues (Barstow, Jones, Nguyen & Casburi, 1996). In the present study, VO_{2max} may have been achieved during the TTE test in both conditions and thus there was no continual rise in VO_2 in the VR condition despite a greater TTE. Often, when a person is working at a high percentage of their VO_{2max}, the mismatch between ATP demand and aerobic ATP provision increases as a function of exercise intensity, thus resulting in an increased rate of lactate production (Spriet, Howlett & Heigenhauser, 2000). A greater increase in b[La] production was not evident in the VR condition in the current study, likely due to VO_2 remaining relatively similar between conditions and thus no added signalling for a high glycolytic activity which may have occurred under further physiological stress (Juel, 2001). To the authors knowledge no research exists whereby VO_2 and b[La] responses to exercise in a VR environment were measured. It appears that the overwhelming majority of studies chose instead to focus on the psychological and perceptual responses to exercise with the addition of VR.

4.3 The Perceptual Responses to Exercising in a Virtual Environment

4.3.1 Rating of Perceived Exertion

In the VR condition in this study there was a *very likely* moderate difference in RPE at minute 2, with RPE 9% lower than CON condition. For minutes 4 and 6 the differences in RPE were *likely* small in comparison, with RPE slightly lower in the VR condition. This data appears to suggest an effect of intensity and/or level of fatigue. Despite the TTE test being a constant power test, the participants were likely influenced to a greater extent by the VR at minute 2 prior to the onset of fatigue which may have occurred in minutes 4 and 6. A study by (Mestre et al 2011b) found lower levels of perceived exertion (7%) in a VR condition when compared to a no feedback (no VR) control condition. In their study participants were asked to cycle at a moderate intensity, specifically a minimal HR of 110 b.min^{-1}, for a duration of 15 minutes. Plante et al (2003a) found that RPE actually increased in a VR condition when participants cycled at 70% maximum HR. This data combined indicates that when VR is utilised at lower intensities it can have a greater effect on RPE than at higher intensities where the task is more taxing and feelings of fatigue are possibly stronger. The effects on RPE at minute 2 are also closely associated with a reduced HR in VR condition at the same time point. According to Robertson (1982), RPE is closely associated with HR. It is suggested that when HR is amplified, the result would be a consistently higher

RPE (Lind, 2008). Inversely, a lower HR would be associated with a lower RPE, similar to that seen in this study at minute 2.

4.3.2 Affect

Results of this study indicated that there was an enhanced affective response to exercise with the use of VR. There was a *very likely* large increase in PA from pre to post exercise in the VR condition compared to a *likely* moderate increase in CON condition. The exposure to external stimuli in the VR condition increased PA from pre to post exercise at over double the rate of that from pre to post in CON condition. A study by Murray et al. (2016) showed that VR increased feelings of PA by 9% compared to a control condition. Increases in PA with the use of VR have also been found by Legrand et al. (2011) and Russell and Newton (2008). However, Legrand et al. (2011) also found similar increases across all experimental conditions, whilst Russell and Newton (2008) compared their VR condition to a video game only control condition. Legrand et al. (2011) found that the use of interactive VR proved to be especially effective in decreasing feelings of NA. In the current study, much like Murray et al. (2016) there were no clear differences in NA between VR and CON trials. Despite changes in PA and NA in the aforementioned studies, the impact of VR was considerably lower than that found using the fully immersive VR apparatus in this study. The heightened feelings of PA experienced by participants in this study may have occurred due to the distraction effect of external sensory stimuli elicited through the immersive VR headset. External sensory stimuli is thought to divert attention from unpleasant bodily sensations towards positive feelings of affect (Dagonneau et al., 2009). This shift in attentional focus is a key contributing factor to the performance improvements discussed above.

4.3.3 Enjoyment

In the current study the PACES questionnaire indicated that there was a *very likely* moderate increase in the level of enjoyment experienced when exercising using VR compared to without. This equated to a 70% increase in enjoyment in the VR condition. Mestre et al. (2011b), Murray et al. (2016) and Plante et al. (2003a), all found that exercising in a VR condition provided a more enjoyable experience for study participants. PACES scores in the studies by Mestre et al. (2011b), Murray et al. (2016) and Plante (2003a) increased by 40%, 8% and 15% respectively with the greatest impact on enjoyment occurring when performing cycling exercise similar to that used in this study. It is evident that enjoyment, measured after exercise in a VR environment, is typically elevated above that recorded in a control condition. These increased feelings of enjoyment are highly associated with long-term exercise adherence (Williams et al., 2008) and thus may be important in overcoming growing levels of inactivity (Legrand et al., 2011).

4.3.4 Attentional Focus

Reductions in RPE, increases in PA and increased levels of enjoyment of exercise whilst immersed in the VR environment found in this study may all have been a result of a shift in attentional focus. A study by Mestre et al. (2011a) described two broad categories of attentional focus that the effects of VR on exercise may be related to: association which refers to an internal attentional focus whereby participants focus their attention on internal bodily sensations and dissociation which refers to an external attentional focus in which participants' attention is diverted from internal sensations to external distracting stimuli (Hutchinson & Tenenbaum, 2007). Mestre et al. (2011a), Mestre et al. (2011b) and Dagonneau et al. (2009) highlight how a shift to an external focus, promoted by the distracting, dissociative thoughts and effects of VR stimulation can lower perception of exertion, increase exercise enjoyment and promote PA. This reinforces the importance of inhibiting the processes of other sensory cues such as cognitions of fatigue in favour of a greater voluntary central drive (Hardy and Rejeski, 1989).

4.3.5 Dissociation and VR

A number of studies using VR in the exercise domain have alluded to the dissociation effect it exerts. Murray et al. (2016) suggested that the sensory input received through their VR environment may have detracted from the discomfort associated with the extra effort exerted, via a dissociation effect. Whilst there is indirect evidence to suggest that a dissociation effect existed in many studies, few have directly measured attentional focus and/or dissociation. Mestre et al. (2011a) and Mestre et al. (2011b) measured study participants attentional focus via gaze analysis and questionnaires respectively. An attentional focus analog scale showed that VR increased dissociation by 15% when compared to a no VR control condition. In the former study gaze orientation, whereby the allocation of attention i.e. time spent looking directly at or away from the screen was recorded (Dagonneau et al., 2009), indicated an increased dissociation effect when exercising in a VR environment. The current study may have benefited from the use of gaze analysis as a tool to assess attentional processes and thus allow direct inferences be made about the link between dissociation and improvements in performance. Finally, research by Dagonneau and colleagues (2009) highlighted how gaze time decreased when exercise intensity increased indicating a complex interaction between attentional focus, exercise intensity and performance.

4.3.6 Immersion and Presence

In order to combat the aforementioned decrease in attentional focus associated with exercising at higher intensities, the level of immersion and subsequent degree of presence felt should be maximised. Ijsselsteijn et al. (2004) showed that in a high immersion condition, where participants rated their experience of presence higher, there was a 51% increase in enjoyment (which is linked to dissociation) compared to low immersion condition, leading to a higher average speed. The VR interface used in the current study offers a similar high level of immersion and thus provided a platform for an intense feeling of presence which could potentially lead to a dissociation effect. However, the degree of presence felt by participants reported in the presence questionnaire had a non-significant weak to moderate positive relationship with the increased TTE in the VR condition. Further VR conditions should be adopted in future studies to examine more thoroughly the relationship between presence and performance.

4.4 Limitations & Future Research

Several lessons can be learned from this study on the use of fully immersive VR in an exercise setting. Firstly, the absence of a VR-control trial whereby participants would have worn the VR equipment with no environment on screen did not allow a novelty effect of using the VR equipment to be ruled out as the reason for performance improvements. Furthermore, in relation to a novelty effect, multisession use of the VR would have identified a possible initial novelty effect. Secondly, at high exercise intensities, external stimuli cannot compete with and override physiological cues in afferent neural pathways (Rejeski, 1985) in a manner that is possible at lower intensities. Therefore the potential to improve performance may be greater at lower exercise intensities and thus warrants further investigation. There remain numerous other avenues for exploration regarding the use of fully immersive VR in an exercise setting. Future studies of this kind should aim to examine the use of VR pre-task, the use of VR with further external stimuli such as music or verbal/written primes, the use of VR with other exercise modalities, and the use of VR and exercise amongst different populations. The VR exercise experience will continue to develop at a fast pace and future research needs to act accordingly to inform this growth.

4.5 Practical Applications

One of the key applications of VR may include its use to elicit greater performance levels in training sessions, particulalry at times when motivation or mood is low. For the recreational athlete, the increased levels of affect and enjoyment associated with VR may lead to greater adherence to exercise programmes and even contribute to increased participation in physical activity. Immersive VR devices have become increasingly mainstream in recent times through avenues such as mobile phones, which may serve to couple as cost-effective devices for health behaviour change. In summary, the use of VR may enable many people to overcome barriers to exercise whether at an elite or recreational level of participation.

4.6 Conclusions

This study has demonstrated that the use of a fully immersive virtual reality headset, running a computer generated virtual environment, during a traditional high-intensity cycling task, increased PA and enjoyment thus increasing TTE. The physiological responses to exercise in the VR environment remained relatively unchanged indicating no additional physiological cost for a greater task performance. These findings support the emerging literature showing that VR can exert several changes in the perceptual response to exercise thus enhancing performance. In conclusion, this study has demonstrated the effectiveness of VR in the exercise domain as a performance enhancing ergogenic aid.

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Appendices

Appendix A. Ethical Approval Letter

Faculty of Science and Engineering
Research Ethics Committee

Gerard Nowlan
Apartment 30 Kings Dock Mill,

32 Tabley Street,
Liverpool,
L1 8DW

29th March 2016

Dear Gerard,

Study title: The physiological and perceptual responses to cycling exercise in a fully immersive virtual reality environment
FSE-REC reference: 028/16/GN/SES
Version number: 2

Thank you for sending your application to the Faculty of Science and Engineering Research Ethics Committee for review.

I am pleased to confirm ethical approval for the above research, provided that you comply with the conditions set out in the attached document, and adhere to the processes described in your application form and supporting documentation.

The final list of documents reviewed and approved by the Committee is as follows:

Document	Enclosed?	Appendix №	Version №	Date
FSE-REC application form	**Mandatory**	1	2	05/02/16
List of references	**Mandatory**	7	2	05/02/16
Brief C.V. for main researcher	**Mandatory**	4	2	05/02/16
Letter(s) of invitation to participants	**NA**			
Participant Information Sheet(s) [PIS]	**Y**	6	3	17/03/16
Participant consent form(s)	**Y**	3	2	05/02/16
Information sheets / letters to people	**NA**			
Written permission from relevant personnel (eg. to use facilities) if required	**NA**			
Interview schedule(s) or topic guide(s) if required	**NA**			
Questionnaire(s) for the study I-PANAS-SF questionnaire PACES questionnaire Pre-test health questionnaire	**Y**	 8 9 10	 3 2 2	17/03/16
Copies of advertisement material(s) if required	**NA**			
Risk Assessment form(s)	**Y**	2	2	05/02/16
Other documents (Please specify below, as necessary)	**Y**			
CV of other individual working on research project	**Y**	5	2	05/02/16

	Y / N			
	Y / N			
	Y / N			
	Y / N			
	Y / N			
	Y / N			
	Y / N			

Please note that this approval is given in accordance with the requirements of English law only. For research taking place wholly or partly within other jurisdictions (including Wales, Scotland and Northern Ireland), you should seek further advice from the Committee Chair / Secretary or the Research and Knowledge Transfer Office and may need additional approval from the appropriate agencies in the country (or countries) in which the research will take place.

With the Committee's best wishes for the success of this project.

Yours sincerely,

Helen Southall
Chair, Faculty of Science and Engineering Research Ethics Committee

Enclosures: Standard conditions of approval.

Cc. Supervisor/FSE-REC Representative

Appendix B. Participant information sheet

University of Chester

Participant information sheet

The physiological and perceptual responses to cycling exercise in a fully immersive virtual reality environment

You are being invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take the time to read the following information carefully and discuss it with others if you wish. Feel free to ask me if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Thank you for reading this.

What is the purpose of the study?
The purpose of this study is to determine whether people respond differently to exercise in two separate conditions (exercise in a virtual reality environment using virtual reality goggles, and exercise in a control condition without virtual reality goggles).

Why have I been chosen?
You have been chosen because you are a healthy, recreationally active adult between the ages of 18-45 capable of carrying out the exercise protocols within this study.

Do I have to take part?
It is up to you to decide whether or not to take part. If you decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect you in any way.

What will happen to me if I take part?
You will be given this information sheet to keep for reference and be asked to sign a participant consent form. You will visit the laboratory on 3 occasions. On the first visit, before any testing can commence you will be talked through a pre-test health questionnaire which will involve answering some questions on your health and then you will have your blood pressure and heart rate measured. Further pre-test measurements including stature and body mass will also be measured. Upon completion of these measurements you will perform a VO_{2max} test on a cycle ergometer to assess your maximal oxygen uptake and to calculate exercise intensity for subsequent visits. This will involve cycling at approximately 80 rpm with an increase in the wattage (difficulty) every 4 minutes. The program will terminate when you drop below 60 rpm and cannot cycle anymore. You will have your heart rate recorded in the final minute of each stage as well as RPE which will require you to indicate on a scale of 6-20 how difficult you find the exercise at hand, and blood lactate sample which simply involves a small prick of the index finger tip using a blood lactate analyser. You will then perform a cool down period until your heart rate returns to near resting levels.

Approximately 3 days later you will visit the lab for the 2nd visit where you will perform a test to exhaustion on a cycle ergometer at 80% of your VO_{2max}. You will be fitted with a mask and connected to an online gas analyser when sat in place in order to measure oxygen consumption. Heart rate, blood lactate, and rating of perceived exertion (RPE) will be recorded every two minutes for the duration of the test. Upon completion of the test, you will cool down until your heart rate returns to near resting levels. You will then complete a brief psychological questionnaire to measure your affective responses to the exercise. This protocol will be repeated on visit 3 to the lab with the only difference being that will also wear headphones and the virtual reality goggles when sat in place.

What are the possible disadvantages and risks of taking part?
Testing requires you to perform maximally during both the VO_{2max} test and the test to exhaustion protocol which can lead to you possibly feeling uncomfortable. Every effort will be taken to ensure you remain safe throughout and after the testing period. After each visit to the laboratory you may also experience some fatigue, however this will be no more than you experience with your usual training or exercise regime and have no long lasting effects. You will be asked to give up approximately 2 hours of your time across 4 separate days of testing for this study.

What are the possible benefits of taking part?
You will be given the results of your VO_{2max} test which will give you an accurate up to date account of your current fitness level. These figures can be of particular benefit when setting training zones to inform training programmes. The study will also allow you gain an insight into the world of sports science testing and provide you with some experience of laboratories that may inform your own interests or studies. In addition, you will be able to gain an insight into the application of virtual reality in the exercise setting which is not yet available commercially.

What if something goes wrong?
If you wish to complain or have any concerns about any aspect of the way you have been approached or treated during the course of this study, please contact Executive Dean of the Faculty of Science and Engineering, University of Chester, Thornton Science Park, Pool Lane, Ince, Chester CH2 4NU 01244 513197

Will my taking part in the study be kept confidential?
All information which is collected about you during the course of the research will be kept strictly confidential so that only the researcher carrying out the research will have access to such information.

What will happen to the results of the research study?
The results will be written up into a dissertation for my final project of my MSc. Individuals who participate will not be identified in any subsequent report or publication.

Who is organising the research?
The research is conducted as part of an MSc in Sports Physiology within the Department of Sport and Exercise Sciences at the University of Chester. The study is organised with supervision from the department, by Gerard Nowlan, an MSc student.

Who may I contact for further information?
If you would like more information about the research before you decide whether or not you would be willing to take part, please contact:

Gerard Nowlan: 1218482@chester.ac.uk

Thank you for your interest in this research.

Appendix C. Informed consent

University of Chester

Title of Project: The physiological and perceptual responses to cycling exercise in a fully immersive virtual reality environment

Name of Researcher: Gerard Nowlan

Please initial box

1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason and without my legal rights being affected. ☐

3. I agree to take part in the above study. ☐

Name of Participant	Date	Signature

Researcher	Date	Signature

1 for participant; 1 for researcher

Appendix D. **Pre-test health questionnaire**

DEPARTMENT OF SPORT AND EXERCISE SCIENCES
UNIVERSITY OF CHESTER

PRE-TEST HEALTH QUESTIONNAIRE

(Please note that this information will be confidential)

Name.………………………………………………… DOB…………………………….

Resting blood pressure (mmHg) ………. /………. Resting heart rate (b.min^{-1}) ……………

Stature……………………………………………. Body Mass……………………………….

Project Title: **The physiological and perceptual responses to cycling exercise in a fully immersive virtual reality environment**

Please answer these questions truthfully and completely. The purpose of this questionnaire is to ensure that you are fit and healthy enough to participate in this laboratory practical/research project.

	Yes	**No**
1. Have you in the past suffered from a serious illness or accident. If Yes, please provide details.	☐	☐

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………..

	Yes	**No**
2. Have you consulted your doctor the last 6 months If Yes, please provide details	☐	☐

…………………………………………………………………………………………………..…
………..…………………………………………………………………………………………
…………………

3. Do you suffer, or have you suffered from:

	Yes	**No**
Asthma	☐	☐
Diabetes	☐	☐
Bronchitis	☐	☐
Epilepsy	☐	☐
High blood pressure	☐	☐

	Yes	**No**
4. Is there any history of heart disease in your family	☐	☐

	Yes	**No**
5. Are you suffering from any infectious skin diseases, sores, wounds, or blood infections i.e., Hepatitis B, HIV, etc.? If Yes, please provide brief details.	☐	☐

……………………………………………………………………………………………………
……………………………………………………………………………………………………
………………

	Yes	No
6. Are you currently taking any medication If Yes, please provide details.	☐	☐

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………

	Yes	No
7. As far as you are aware, are you pregnant?	☐	☐
8. Are you suffering from a disease that inhibits the sweating process	☐	☐
9. Is there anything to your knowledge that may prevent you from participating in the testing that has been outlined to you? If Yes, please provide details.	☐	☐

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………

Your Recent Condition

	Yes	No
• Have you eaten in the last 2 hours? If Yes, please provide details	☐	☐

……………………………………………………………………………………………………
……………………………………………………………………………………………………
………………

- Evaluate your diet over the last two days. **Poor** **Average** **Good** **Excellent**

	Yes	No
• Have you consumed alcohol in the last 24hr	☐	☐
• Have you had any kind of illness or infection in the last 2 weeks	☐	☐
• Have you exercised in the last 2 days?	☐	☐

If Yes, please describe below

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………

Persons will not be permitted to take part in any experimental testing if they:-

- have a known history of medical disorders (i.e. hypertension, heart or lung disease)
- have a fever, suffer from fainting or dizzy spells
- are currently unable to train because of a joint or muscle injury
- have had any thermoregulatory disorder
- have gastrointestinal disorder
- have a history of infectious diseases (i.e. HIV or Hepatitis B)
- have, if pertinent to the study, a known history of rectal bleeding, anal fissures, haemorrhoids or any other similar rectal disorder.

My responses to the above questions are true to the best of my knowledge and I am assured that they will be held in the strictest confidence.

Name: (Participant)………………………………………… Date:………………….

Signed (Participant): ………………………………………

Name: (Lecturer/technician)………………………………. Date:………………….

Signed (Lecturer/technician): ………………………………

Appendix E. Written Food Diary

24 Hour Food Diary Name:

Time	Food/Drink	Amount	Physical Activity

Appendix F. BASES criteria for establishing VO_{2max}

Criteria for establishing maximal oxygen uptake in adults (BASES, 1997)
. A plateau in the oxygen uptake-exercise intensity relationship. This is defined as an increase in oxygen of less than 2 ml.kg-1 .min-1 or 3% with an increase in exercise intensity. If the plateau is not achieved the term vo2 peak is preferred.
. A final respiratory exchange ratio (RER) ≥1.15.
. A final heart rate of within 10 b.min-1 of the predicted age-related maximum (ie. 220-age).
. Subjective fatigue and volitional exhaustion.
. An RPE of 19 or 20 on the Borg 6 to 20 RPE scale.
. A post exercise (4-5 min) blood lactate concentration >8 mmmol.-1

Appendix G. I-PANAS-SF

The International Positive and Negative Affect Schedule Short Form (I-PANAS-SF) Question, Measure, and Item Order

1.Upset	❒1	❒2	❒3	❒4	❒5
2. Hostile	❒1	❒2	❒3	❒4	❒5
3. Alert	❒1	❒2	❒3	❒4	❒5
4. Ashamed	❒1	❒2	❒3	❒4	❒5
5. Inspired	❒1	❒2	❒3	❒4	❒5
6. Nervous	❒1	❒2	❒3	❒4	❒5
7. Determined	❒1	❒2	❒3	❒4	❒5
8. Attentive	❒1	❒2	❒3	❒4	❒5
9. Active	❒1	❒2	❒3	❒4	❒5
10. Afraid	❒1	❒2	❒3	❒4	❒5

To what extend do you feel…

Interval measure: *1.strongly disagree 2. Disagree 3.neither agree or disagree 4. Agree 5. Strongly agree*

Appendix H. PACES, Physical activity enjoyment scale

When I am active… (1) Disagree a lot … (5) Agree a lot

1. I enjoy it	❒1	❒2	❒3	❒4	❒5
2. I feel bored	❒1	❒2	❒3	❒4	❒5
3. I dislike it	❒1	❒2	❒3	❒4	❒5
4. I find it pleasurable	❒1	❒2	❒3	❒4	❒5
5. It's no fun at all	❒1	❒2	❒3	❒4	❒5
6. It gives me energy	❒1	❒2	❒3	❒4	❒5
7. It makes me depressed	❒1	❒2	❒3	❒4	❒5
8. It's very pleasant	❒1	❒2	❒3	❒4	❒5
9. My body feels good	❒1	❒2	❒3	❒4	❒5
10. I get something out of it	❒1	❒2	❒3	❒4	❒5
11. It's very exciting	❒1	❒2	❒3	❒4	❒5
12. It frustrates me	❒1	❒2	❒3	❒4	❒5
13. It's not at all interesting	❒1	❒2	❒3	❒4	❒5
14. It gives me a strong feeling of success	❒1	❒2	❒3	❒4	❒5
15. It feels good	❒1	❒2	❒3	❒4	❒5
16. I feel as though I would rather be doing something else	❒1	❒2	❒3	❒4	❒5

Appendix I. Presence questionnaire

Characterize your experience in the environment, by marking an "X" in the appropriate box of the 7-point scale, in accordance with the question content and descriptive labels. Please consider the entire scale when making your responses, as the intermediate levels may apply. Answer the questions independently in the order that they appear. Do not skip questions or return to a previous question to change your answer.

WITH REGARD TO THE EXPERIENCED ENVIRONMENT….

1. How much were you able to control events?

NOT AT ALL **SOMEWHAT** **COMPLETELY**

2. How responsive was the environment to actions that you initiated (or performed)?

NOT RESPONSIVE **MODERATELY RESPONSIVE** **COMPLETELY RESPONSIVE**

3. How natural did your interactions with the environment seem?

EXTREMELY ARTIFICAL **BORDERLINE** **COMPLETELY NATURAL**

4. How much did the visual aspects of the environment involve you?

NOT AT ALL **SOMEWHAT** **COMPLETELY**

5. How much did the auditory aspects of the environment involve you?

NOT AT ALL SOMEWHAT COMPLETELY

6. How natural was the mechanism which controlled movement through the environment?

EXTREMELY ARTIFICAL BORDERLINE COMPLETELY NATURAL

7. How compelling was your sense of objects moving through space?

NOT AT ALL MODERATELY COMPELLING VERY COMPELLING

8. How much did your experiences in the virtual environment seem consistent with your real world experiences?

NOT CONSISTENT MODERATELY CONSISTENT VERY CONSISTENT

9. Were you able to anticipate what would happen next in response to the actions that you performed?

NOT AT ALL SOMEWHAT COMPLETELY

10. How completely were you able to actively survey or search the environment using vision?

NOT AT ALL SOMEWHAT COMPLETELY

11. How well could you identify sounds?

NOT AT ALL SOMEWHAT COMPLETELY

12. How well could you localize sounds?

NOT AT ALL SOMEWHAT COMPLETELY

13. How well could you actively survey or search the virtual environment using touch?

NOT AT ALL SOMEWHAT COMPLETELY

14. How compelling was your sense of moving around inside the virtual environment?

NOT COMPELLING MODERATLEY COMPELLING VERY COMPELLING

15. How closely were you able to examine objects?

NOT AT ALL PRETTY CLOSELY VERY CLOSELY

16. How well could you examine objects from multiple viewpoints?

NOT AT ALL SOMEWHAT EXTENSIVELY

17. How well could you move or manipulate objects in the virtual environment?

NOT AT ALL SOMEWHAT EXTENSIVELY

18. How involved were you in the virtual environment experience?

NOT INVOLVED MILDLY INVOLVED COMPLETELY ENGROSSED

19. How much delay did you experience between your actions and expected outcomes?

NO DELAYS **MODERATE DELAYS** **LONG DELAYS**

20. How quickly did you adjust to the virtual environment experience?

NOT AT ALL **SLOWLY** **LESS THAN ONE MINUTE**

21. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?

NOT PROFICIENT **REASONABLY PROFICIENT** **VERY PROFICIENT**

22. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

NOT AT ALL **INTERFERED SOMEWHAT** **PREVENTED TASK**
PERFORMANCE

23. How much did the control devices interfere with the performance of assigned tasks or with other activities?

NOT AT ALL **INTERFERED SOMEWHAT** **INTERFERED GREATLY**

24. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

NOT AT ALL **SOMEWHAT** **COMPLETELY**

25. How completely were your senses engaged in this experience?

NOT ENGAGED **MILDLY ENGAGED** **COMPLETELY ENGAGED**

26. To what extent did events occurring outside the virtual environment distract from your experience in the virtual environment?

NOT AT ALL **MODERATELY** **VERY MUCH**

27. Overall, how much did you focus on using the display and control devices instead of the virtual experience and experimental tasks?

NOT AT ALL **SOMEWHAT** **VERY MUCH**

28. Were you involved in the experimental task to the extent that you lost track of time?

NOT AT ALL **SOMEWHAT** **COMPLETELY**

29. How easy was it to identify objects through physical interaction; like touching an object, walking over a surface, or bumping into a wall or object?

IMPOSSIBLE **MODERATELY DIFFICULT** **VERY EASY**

30. Were there moments during the virtual environment experience when you felt completely focused on the task or environment?

NONE **OCCASSIONALY** **FREQUENTLY**

31. How easily did you adjust to the control devices used to interact with the virtual environment?

DIFFICULT **MODERATE** **EASILY**

32. Was the information provided through different senses in the virtual environment (e.g., vision, hearing, touch) consistent?

NOT CONSISTENT **SOMEWHAT CONSISTENT** **VERY CONSISTENT**

Appendix J. Detailed description of Questionnaires

I-PANAS-SF

Participants completed a brief Likert scale questionnaire called The International Positive and Negative Affect Schedule Short Form (I-PANAS-SF) prior to, and immediately following each TTE test. The original version of the PANAS developed by Watson, Clark and Tellegen (1988) was deemed quite long for studies involving numerous other variables and for use with time constrained populations. Therefore the shortened version developed by Thompson (2007) was considered to be more suitable for this study, given that it also helps avoid problems of vagueness and ambiguity within participants answers. The questionnaire was employed to measure positive and negative dimensions of affect on arrival to the lab and the resultant positive and negative dimensions of affect arising from the TTE tests. The questionnaire contains the question ‘to what extent do you feel’ followed by ten different affect states, which participants are required to rate from 1-5. Ratings of 1 mean strongly disagree, with 5 meaning strongly agree. The scores were added together to determine overall positive (PA) and negative affect (NA) prior to and following each TTE test.

PACES

Enjoyment of physical activity was measured immediately following each TTE test using the Physical Activity Enjoyment Scale (PACES). PACES was originally designed by Kendzierski and DeCarlo (1991), then later refined and simplified by Motl et al. (2001). The shortened version was deemed more appropriate for this study due to the number of questionnaires within the study and the ease of understanding for participants. The scale consists of the words ‘when I am active’ followed by 16 statements relating to physical activity including ‘I enjoy it’ and ‘it’s not at all interesting’. Participants were required to respond to each statement on a Likert scale ranging from 1 (totally disagree) to 5 (totally agree). Positive statement scores such as ‘I enjoy it’ were calculated at face value whilst the values of negative statement scores such as ‘It frustrates me’ were reversed scored. Item scores were then summed to form a unidimensional measure of enjoyment. PACES is the most widely used measure of physical activity enjoyment (Mullen et al., 2011) and has been used in previous research on VR in the exercise domain (Murray et al., 2016).

Presence Questionnaire

A 32 item Likert scale questionnaire called the Presence Questionnaire (PQ) (Witmer & Singer, 1998) was completed by participants immediately following the TTE test involving the VR headset. The PQ measures the degree to which individuals experience presence in the virtual environment and the influence of possible contributing factors on the intensity of that experience (Witmer & Singer, 1998). PQ items encapsulate both aspects of presence: involvement and immersion. The PQ uses a seven point scale format based on the semantic differential principle (Dyer, Matthews, Stulac, Wright & Yudowitch, 1976). However, unlike semantic differential, the scale includes a midpoint anchor. Participants will be asked to place an “X” in the appropriate box of the scale in accordance with the question content and descriptive labels (see Figure 2.2). The scale ranges from 1-7 with final scores of the 32 items summated to give an overall rating of presence.

18. How compelling was your sense of moving around inside the virtual environment?

NOT COMPELLING | MODERATELY COMPELLING | VERY COMPELLING

Figure. An exemplar item from the presence questionnaire